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A Systematic Comprehensive Review and Synthesis of Different Mechanisms of Action for Scoliosis Braces in English and French Literature

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ABSTRACT

A very wide variety of braces have been developed around the world during the last decades. This diversity often complicates therapeutic decisions. It is, therefore, more pragmatic to categorize braces based on their mechanisms of action. This study aims to identify and classify these mechanisms into three categories: passive, active, and secondary.

To achieve this, a comprehensive review of existing literature in both English and French was conducted following the PRISMA diagram. 1575 articles were identified. After removing duplicates, 69 articles were found to highlight 24 mechanisms of action: comprising 12 passive, 6 active, and 6 Secondary.

12 Passive Mechanisms are Including: 1. Concave to convex tissue transfer under T10, 2. Rib-cage/spine coupling patterns between T2-T10, 3. plane geometry, 4. solid geometry, 5. Three-point system or derotation torque, 6. Derotation on Z axis, 7. global bending, 8. regional bending, 9. mobility under the brace, 10. Unloading, 11. recentering of the apical nucleus, and 12. sagittal normalization.

6 Active Mechanisms are Including: 1. vertebral growth modulation, 2. rebalance stress distribution, 3. active pulling, 4. active pushing, 5. elastic forces, 6. Ponseti-type intervention.

6 Secondary Mechanisms are Including: 1. vital capacity, 2. material tolerance, 3. closures, 4. Physiotherapy & gait modification, 5. Management, 6. Monitoring.

Generic braces are a testament to the geographical schools of thought and research experiences from which they originate. The ideal brace remains nameless, as it represents a balanced choice of action mechanisms, striving for a compromise between effective three-dimensional correction and patient tolerance.

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Introduction

In recent history, all the teams involved in the non-surgical conservative treatment have developed their own technic, from available means and materials. Some old designed braces are still used today, for their specific properties. Efforts to categorize these braces based on their mechanical functions tend to focus on their primary action or corrective approach.

The Milwaukee brace, a cornerstone in the development of modern scoliosis braces, operates through three key mechanisms: longitudinal distraction, transverse re-centering force, and active apical remodeling. These mechanisms work in tandem to provide effective spinal correction and support [1].

The EDF plaster cast and the Lyon brace introduce two additional mechanisms: flexion and derotation [2].

In 2006, the consensus on the bio-mechanical action of braces was a failure [3,4].

More recent syntheses are limited to the main action of the braces in 6 items: bending, detorsion, elongation, movement, push-up, three points [5,6].

The mechanical design and function of scoliosis braces have undergone significant evolution, adapting to various needs over time. This evolution can be categorized into three main areas: axial, surface, and temporal.

Axial Evolution

Initially, braces focused on geometric detorsion along the Z-axis, which was more effective for correcting large spinal angles. Over time, the focus shifted to mechanical detorsion along the X and Y axes, better suited for addressing smaller curves. While many braces claim to offer 3D correction across all spatial planes, only a few effectively utilize solid volumetric geometry to achieve this [7].

Surface Evolution
The design of scoliosis braces has also transitioned from long to shorter forms. Examples of this evolution include the shift from Milwaukee to Boston braces, Chêneau to Gensingen, and Lyon to 3-point and GTB systems. However, a challenge with shorter braces is the potential risk of inducing counter-curves [8].

Temporal Evolution
The duration of brace wear has changed from permanent to primarily nocturnal use. Permanent wear facilitates the plastic deformation of the concave and convex ligamentous structures. In contrast, nocturnal wear allows for hypercorrection, particularly beneficial before the age of 12, as it aids in recentering the nucleus of the apical intervertebral disc.

In summary, the evolution of scoliosis braces reflects a nuanced understanding of spinal correction, with each advancement aiming to enhance effectiveness while minimizing potential drawbacks [9,10].

Young's Modulus: From Rigid to Elastic Braces
Young's modulus is a measure of a material's rigidity. In the context of braces, a flexible brace permits trunk movement while maintaining consistent skin pressure during motion. Interestingly, when a child actively avoids contact with a rigid brace, the skin pressure decreases. This reduction in pressure encourages corrective movement within the confines of the rigid brace [11].

Dynamic Evolution: From Fixed to Mobile Contact
The rib cage naturally expands and contracts with each breath. However, using a permanent contact, such as a metal or carbon blade, during breathing can inadvertently consume some of the energy required for this natural process. Transitioning to a more dynamic support system that accommodates these changes can enhance comfort and efficiency [9].

Sagittal Evolution: From the Frontal Plane to the Sagittal Plane
Traditionally, scoliosis and the use of braces have been primarily evaluated from the frontal plane. Most corrective moldings were designed with a focus on achieving corrected lordosis. However, recent insights have shifted this perspective towards the sagittal plane. This evolution is driven by the need to address the risk of increased retroversion in adulthood and the potential for assessing sagittal normalization based on pelvic incidence.

This new approach offers significant advantages, particularly in promoting lumbar rotation. By utilizing selective contact at the level of the transverse convexity, practitioners can achieve more effective correction. This method not only enhances the overall alignment but also contributes to better long-term outcomes for individuals with scoliosis [10-12].

Materiel and Methods
Protocol
This systematic review was performed according to the PRISMA statement [13].

Search Methods and Study Selections
A systematic review was carried out to search for publications describing one or more mechanisms of action of braces for scoliosis in English literature (Medline, Cochrane library, Google scholar, brace patent, Reference manual), but also in French literature (authors personal library and Proteor company).

Articles were considered for inclusion if they discussed the biomechanics of braces, while those focused on modeling and simulation the scoliotic spine were excluded.

Synthesis
Each of the authors listed all the mechanical actions described with their reference. Several synthesis meetings made it possible to group and classify the mechanisms of action into 3 groups: passive, active and secondary

Definition of Mechanical Actions
The ways in which action mechanisms operate can be categorized into three distinct types: passive, active, and secondary.

Passive Mechanisms are those that performs its functions without recourse to an external energy source. And directly address and rectify the scoliotic curvature.

Active Mechanisms, on the other hand, engage with principles of growth or gravity, the physiological functions of ligaments, and require either active participation from the patient or involve breathing exercises [13].

Secondary Mechanisms have dual aspects; they can be advantageous, serving to benefit the child, or detrimental, such as causing a decrease in Forced Vital Capacity [14].

Results
Search
In total, 1393 articles were identified from the English-language literature. Out of these, 260 articles were retained because they addressed at least one mechanism of action of the brace. Additionally, 22 pertinent articles were sourced from French literature, culminating in 282 articles. After removing duplicates, 69 articles were found (Figure 1).

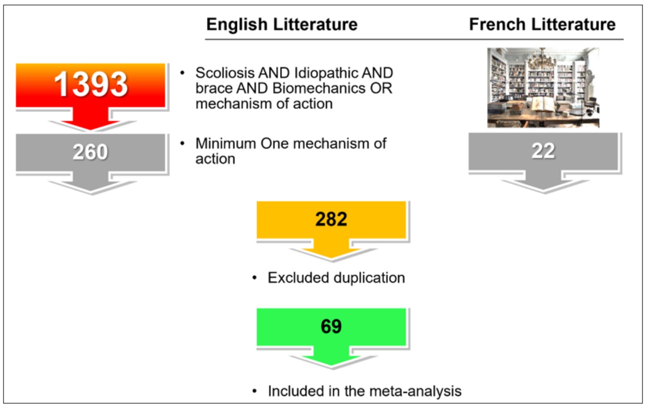

Figure 1: Flowchart of Literature

Study Characteristic
The grouping of the 24 mechanisms of action was streamlined by leveraging the combined 100 years of research and teaching experience of the two authors. Each author has developed a unique brace: GTB for FB and ARTbrace for JCdM [15,16]. Notably,

JCdM is also a trained biomechanic, which informed the decision to present the mechanical actions through a biomechanical lens, adopting a holistic approach.

Distinguishing between passive and active actions proved challenging, as most authors consider their braces to be both three-dimensional and active. In exploring secondary actions, the concept of tolerance was initially debated by the Certified Prosthetist Orthotist (CPO). Ultimately, it was retained, acknowledging that some braces are designed based on X-ray imaging, while others are directly molded on the patient. In both scenarios, the mechanisms of action differ. However, it's important to note that all modern braces, including the Boston brace—historically constructed from modules—are now custom-made based on precise molding techniques. Consequently, we have removed this criterion from consideration [17].

Passive Mechanisms of Action

To begin with, the mechanisms of passive action will be explored. These systems operate independently, requiring no external energy supply. The correction of the curve is achieved directly through the tightening of the brace.

Unlike surgical procedures that rectify scoliosis at the vertebral body level, the brace exerts its corrective influence through the ribcage above the T10 vertebra and engages soft tissue below this point. Generic designs of braces are adjustable to accommodate a diverse range of curves and angles. The Milwaukee brace is particularly versatile, capable of adapting to nearly any curvature. The initial six mechanisms that operate passively are associated with criteria that are anatomical, geometric, and biomechanical in nature.

A key anatomical factor is whether the apical vertebra is situated above or below the T10 vertebra.

Scoliosis presents itself as a deformity occurring in three dimensions. Typically, X-rays are captured in the frontal and sagittal planes, which led to the natural progression of braces utilizing plane geometry. Most of these braces employed a three-point system targeted at the plane where the curvature was most pronounced [18]. It was not until later advancements that detorsion braces were introduced, prominently featuring Dubousset's 3D brace, which applied solid geometry principles for correction along the X, Y, and Z axes [19] (Figure 2).

Figure 2: Ubousset's 3D Brace

Convex to Concave Tissue Transfer Under T10

Regarding the segment of the curve positioned beneath T10, the transfer of soft tissue fundamentally encompasses three distinct mechanisms:

a) The initial mechanism involves directing soft tissue towards the concave side within the frontal plane (concave expansion). This principle finds its application in Chêneau braces [13].
b) The subsequent mechanism is characterized as a push-up approach. Instead of expanding into the concave side, a sort of wall is formed, facilitating the transfer from the base upwards, which is illustrated by the Boston and Sforzesco braces [20,21]. The dynamics occur within the frontal plane and are executed through translation along the Z axis.
c) In 1998, this outcome can be further enhanced by incorporating a convex iliac plateau, a concept initially introduced in the Michel 3-point brace and subsequently adopted in both the GTB short brace [22]. The transfer of soft tissue from the convexity to the concavity is accentuated and the convex costoclavicular oblique orientation creates a "lifting" effect, as in the ARTbrace [16] (Figure 3).

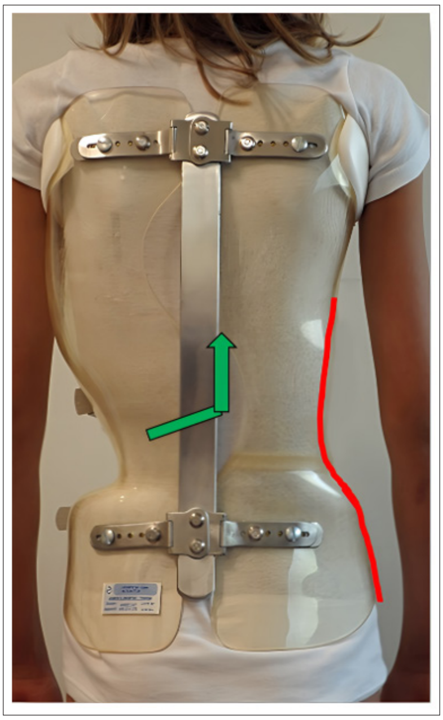

Figure 3: Translation Below T10 by Iliac Plateau with Push-up and Lifting

Rib Cage/Spine Coupling patterns T2-T10

For the section of the curve situated above T10, the mechanical influence on the spine is primarily facilitated through the ribs [23]. Unlike surgery, which acts directly on the spine, the force exerted on the rib is transmitted simultaneously to two vertebral bodies. The apical vertebra is pushed towards the C7 midline when the hump is **regular in** shape, however when it is **angular**, there is a risk of **bending**, limiting translation.

a) The Chêneau brace operates on the principle of translation, featuring **maximal expansion within the concavity** [13,18].
b) Asymmetry might be restricted to bending, with contact occurring in the concavity during deep inhalation, similar to the ARTbrace [16] (Figure 4).

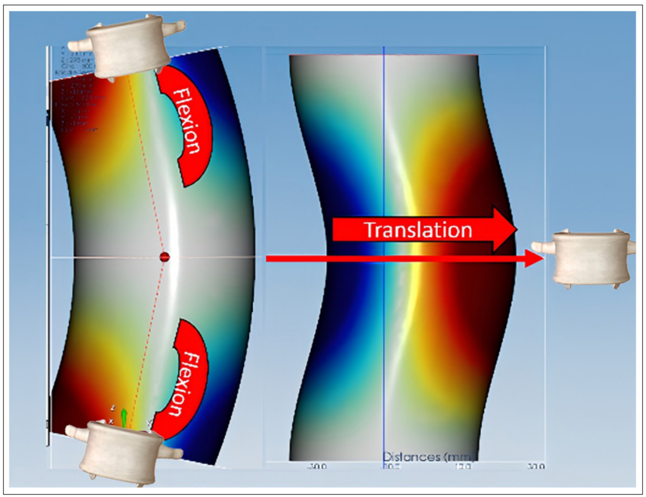

Figure 4: Flexion Changes the Angle of the limit Vertebrae and Lengthens the Concavity

The apical vertebra is fixed at the center of the flexion.

C) Alternatively, the brace can be designed symmetrically without any concave expansion, as exemplified by the Sforzesco brace. In this case, a convex pad enables the transfer, allowing the concave ribs to revert to their natural position upon making contact with the brace. Symmetrical braces prove to be more effective when the angulation is pronounced [21].

3D Plane Geometry
Planar 3D geometry is the most commonly used in surgery. For bracing, the mechanical action on the spine is also analyzed in the 3 planes of space.

a) In the **frontal plane**, the curvature can be adjusted through **bending**. This adjustment involves a **flexion with a varying volume**, characterized by an increased length of the concave side and the contraction of the convex side, which is particularly significant at the thoracic level [16]. **Translation** occurs at a **constant volume** without concave lengthening, facilitating activities such as push-ups and lumbar lifts [18] (Figure 3).
b) In the oft-overlooked **sagittal plane**, corrections made in the frontal plane frequently result in a diminished curvature in the sagittal plane, similar to the effects seen with the Milwaukee brace. For a long time, **corrected lordosis** was the standard approach, as demonstrated by the Boston and the PASB brace [24,25]. The advantage is that it creates a **push-up effect in the sagittal plane**, which is the basis of how the braces work [26].
Most braces accentuate a flat back [27]. The idea of physiologically restoring curves in the sagittal plane emerged with the work of Duval Beaupère on pelvic incidence and the possibility **of sagittal isostatic balance restauration**. The restoration of physiological kyphosis allows for an optimal distribution of stress during mobilization in the sagittal function plane [16].
c) In the **horizontal plane, derotation** can be accomplished by applying pressure on the convex side or by exerting anterior pressure with posterior expansion on the concave side. The degree to which the sagittal plane is altered depends on the orientation of the torque applied [28].

3D Solid Axial Geometry
Solid geometry is particularly well-suited for the application of braces, as the structure of the trunk closely resembles a **hyperboloid** with a central Z axis of symmetry and horizontal cross-sections that form hyperbolas. In contrast, scoliosis can be visualized as a **circled helicoid**, characterized by a **horizontal generating circle** [16] (Figure 5).

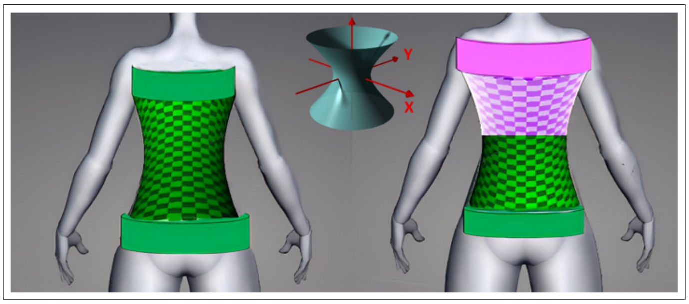

Figure 5: Trunk Hyperboloid Modeling

a) The pioneering experiment conducted by Lewis Sayre serves as an exemplary demonstration of geometrical detorsion in action. When pressure is applied along the vertical Z-axis, it induces a scoliotic deviation; however, by applying traction in the same Z-axis direction, the scoliosis can be effectively corrected. This fundamental concept underpins Lewis Sayre's method of axial traction plaster correction [29]. Successful detorsion necessitates the use of two rigid bases located at the extremities. Consequently, detorsion braces must be anchored at the scapular and pelvic girdles. This movement along the Z-axis is referred to as geometrical detorsion. Among the exercises employed by physiotherapists, self-extension is the most commonly practiced.
b) Mechanical detorsion is accomplished through the simultaneous movement of the orthogonal X and Y axes. This method of coupled movements offers the advantage of selecting two specific planed, which is typically the frontal and sagittal radiological planes. The process of detorsion arises from the interactions of movements within these sagittal and frontal planes [16]. The greatest effect of mechanical detorsion is observed at the level of the apical vertebra, gradually diminishing as it approaches the limiting vertebrae. The "3D brace" from Dubousset was the first to demonstrate the immediate 3D correction [30].

Points or Derotating Force Couple
The three-point system, with one support and two counter-supports, is the most commonly used in most braces. The Chêneau brace maximizes the three-point actions in the maximum curve deformation plan [28].

At the level of the hump and in a horizontal plane, a **two-point system** forms a derotation couple. The same is true at the lumbar level when selective support is provided on the transverse convex. This is one of the advantages of physiological lumbar lordosis [13,18].

Direct Derotation along the Z Axis
Rotation correction along the Z-axis is the second key element in Cotrel's EDF casting technique [31]. Its range is restricted due to the alignment of the posterior articular facets and the intervertebral disc's poor ability to withstand rotational forces [32].

The use of a continuous dynamic contact during derotation likely helps to reduce excessive stress on the disc [33].

Bending Global (Hypercorrecting Braces)
When an individual stands or sits, the presence of sagittal curves is noticeable; however, these curves tend to diminish when the person lies supine, thereby facilitating an emphasis on the brace's action in the frontal plane flexion. These braces, specifically designed for nighttime use, aim for hypercorrection. In cases where there is a singular curve, the bending is considered global, whereas with dual curves, the bending may be localized. The primary function of these nocturnal hypercorrective braces is to realign the nucleus of the intervertebral disc, a task made easier by the absence of gravitational pull and discal night rehydration.

The first nocturnal hypercorrective corset to make its mark was the Charleston bending brace, specifically designed for addressing single curvature issues [34].

Regional Bending
In contrast, for double curvatures, the Providence brace is employed, as it effectively targets two distinct areas: the thoracic and lumbar regions. These nocturnal hypercorrective braces, however, are not suitable for daytime use. This is due to the fact that the pelvic and scapular girdles are positioned at an angle to facilitate the bending process, which disrupts balance when attempting to stand upright [35].

When there arises a necessity for wearing a brace during daylight hours, the financial burden of purchasing two separate braces-one for nighttime and another for daytime-becomes a significant concern, particularly when considering the complexities of sagittal curves and girdle balance. In response to this challenge, Rigo and Wood have made noteworthy compromises grounded in Chêneau's foundational principles. These adjustments are notably challenging to implement and replicate, as they must harmonize frontal correction with the preservation of sagittal curves while maintaining equilibrium between the scapular and pelvic girdles [36].

Mobility Inside the Brace
a) Compliance with brace usage is partly determined by the level of mobility they allow. Tissue braces provide nearly unrestricted mobility [37].
b) In earlier times, braces primarily consisted of leather or fabric mounted onto a metal framework. However, with the advent of petrochemical advancements, materials such as celluloid and ultimately plastic were introduced to the design. This evolution significantly enhanced the rigidity and corrective efficiency of the braces but at the expense of diminishing the wearer's mobility within the device. The development of solid geometry has mitigated this trade-off, as evidenced by innovations like the Milwaukee brace, which focuses on geometric detorsion [38], and the ARTbrace, which adeptly integrates both geometric and mechanical detorsion. The points of contact within the brace vary depending on whether the individual is standing, sitting, or lying down.
The brace then acts like a slide or a bobsleigh track [16,39].
c) Symmetrical braces fitted with internal pads significantly limit mobility, while asymmetrical braces without opposing direction pads offer partial movement. In essence, a brace devoid of internal pads can be likened to a sled operating in reverse to counteract the scoliotic deviation.

Unloading
The reduction of pressure at the vertebral body level is achieved through the composite beam design of braces, which ensures extensive contact surfaces. In the era when lumbar braces were crafted to address disc ailments, Ferrera documented a notable 25% decrease in intradiscal pressure with an inflated vest [40]. This phenomenon is associated with the "composite beam" theory, which emerged from France thanks to Rabishong. The brace's outer casing absorbs a portion of the axial forces, channeling them directly from the shoulder girdle down to the pelvis. The soft tissues help distribute the pressure between the spine and the shell of the brace. This mechanism enhances the function of the soft tissues and diminishes the spine's tendency to buckle, a concept akin to the support provided by a wrestler's belt. The relief in pressure, particularly at the apex of the vertebra, is most pronounced in braces that maintain symmetry [41] (Figure 6).

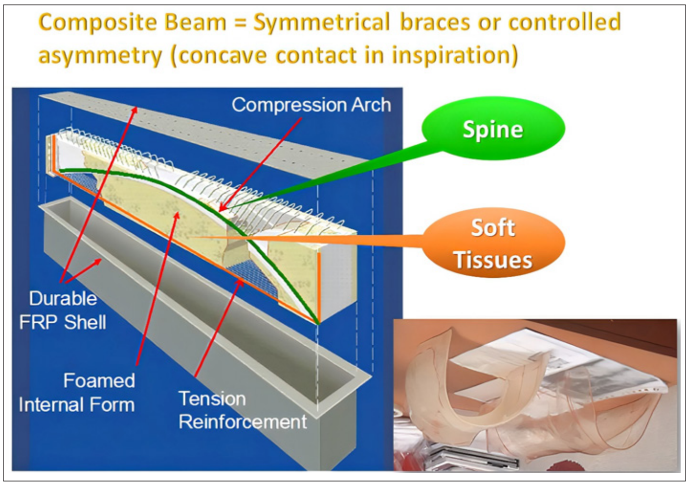

Figure 6: Rabishong's Composite Beam

Apical Nucleus Recentering
In cases of scoliosis, the nucleus of the apical vertebra often shifts towards the convex side, which hinders the scoliosis correction process. Night-time hypercorrective braces are designed to realign the nucleus with the midline, especially since pressure is minimized when lying down. Furthermore, during the night, the disc, which often compresses throughout the day, rehydrates and aids in its repositioning.

This mechanism works in young children under the age of 12. Thereafter, the tensioning of the ligaments with pubertal growth creates a functional Tensegrity with an increase in the disc load [42].

Sagittal Modification
We have discussed the sagittal plane in plane geometry and the importance of the sagittal plane in coupled movements. Piet van Loon has observed that in some thoraco-lumbar scoliosis conditions, merely inducing thoraco-lumbar lordosis can rectify the scoliosis. The TLI brace demonstrates the critical role of the sagittal plane in correcting deformities on the frontal plane. The restoration of sagittal plane curves, accompanied by isostatic balance, has been further enhanced through research linking sagittal curves to the lumbopelvic incidence [43].

Certain mechanisms are complementary and can be combined, while others require making a selection based on priorities (Table 1).

Table 1: Passive Mechanisms of Action

	Passive Mechanisms of Action	Keywords
1	Concave to convex tissue transfer [under T10]	Concave expansion/ Concave wall (push-up) / Concave iliac plateau (lifting)
2	Rib-cage/spine coupling patterns [T2-T10]	Convex correctiong contact | Concave expansion or not
3	3D plane geometry with apical derotation	Flexion / translation | Derotation through convexity or concavity
4	3D solid geometry with detorsion	Hyperboloïd | Geometrical & Mechanical detorsion by coupled movements
5	3 points or derotating force couple	One Force and two counterforces applied proximally and distally to the first one
6	Z axis elongation or coupled movements	Translation along the Z axis
7	Bending global or regional	For one or two curves | with or without girdles
8	Lumbar Lordosis or delordosis	Derotation with lordosis | Sagittal push-up with delordosis & pelvic grip
9	Mobility inside the brace	Neck ring – Soft tissue | Oriented Sliding | Escape Pads
10	Unloading	(Composite beam law) Maximum surface contact
11	Apical nucleus recentering	Night hypercorrecting braces < 11 years
12	Sagittal normalization	Isostatic balance / pelvic incidence

Active Mechanisms of Action

Active mechanisms encompass all the brace's interactions with the body's natural processes, such as growth, respiration, postural stability, and viscoplasticity. The engagement of the patient plays a crucial role in enhancing these active mechanisms. In the Lyon Method, physiotherapy is consistently paired with the use of the brace to activate these mechanisms effectively. Additionally, the brace influences the child's behavior, affecting their interactions within the family, at school, and in social settings. The involvement of a specialized psychologist can further facilitate a positive adjustment to this new dynamic with their surroundings.

Vertebral Growth Modulation

Wolff's law posits that bone development and resorption occur in response to the specific stresses it endures. This principle is further refined at the growth plate level by the Hueter-Volkmann law [44,45].

Such asymmetry is also evident in the intervertebral discs and surrounding soft tissues. The entirety of this process is encapsulated in Ian Stokes' concept of a vicious cycle. However, when a brace achieves a correction exceeding 50%, it effectively interrupts and reverses this detrimental cycle [46].

During the night, the body experiences growth spurts due to the secretion of growth hormone and melatonin, resulting in a nightly increase of approximately 8 millimeters. This physiological phenomenon underscores the efficacy of nocturnal hypercorrective braces [47].

Ultimately, the success of treatment is determined not by the initial Cobb angle but by factors such as the initial deformity of the apical vertebral body, the outward protrusion of the intervertebral nucleus, and the stiffness of the paravertebral soft tissues [13].

Rebalance Stress Distribution

Restoring the balance in relation to the C7midline must be complementary to the angular correction [48].

This mechanism of action is used mainly in adult patients, who more frequently present with imbalances of the occipital axis. Molding is carried out in a re-balanced position in both the frontal and sagittal planes [49]. Additional correction can be obtained during the fitting for braces with two adjustable lateral hemi-valves, either by a shearing effect along the Z axis or by translation under the arm along the Y axis.

Active Body Pulling

The quest to discover active mechanisms that could enhance passive ones first began with geometrical detorsion in the Milwaukee brace.

The active longitudinal distraction technique is designed to alleviate strain on the cervical collar and chin support [50]. For braces featuring underarm support, the upper trim line initially maintains the shoulders in an elevated position. Over time, the shoulders naturally lower from this elevated line, aided by a detorsion effect similar to a two-pronged corkscrew. This rapid lowering typically occurs within the first three days and can continue for up to three weeks [16].

Active Body Pushing and Breathing Mobilization

Another active mechanism involves providing costal support through the use of a metal or carbon blade, which works in harmony with respiratory movements. Additionally, posterior closure braces that focus on stabilizing the abdomen make use of abdominal breathing to facilitate the translation of soft tissues. The vertical support of the blades can be lateral or posterior median. Constant pressure at the level of the ribs and the use of respiratory mechanical energy can be limitations [33,51].

Most braces exert their primary influence during inhalation, a time when they make the most contact with the body. Those braces that maintain a constant convex contact apply a steady pressure throughout the entire breathing cycle, much like fabric braces do. Despite this, the effectiveness of such a mechanism is not always guaranteed, as evidenced by the ineffectiveness of braces like the Olympe brace [52].

Maintaining Brace Effectiveness: The 4th Dimension

There is a correlation between the tightness of the brace and the pressure on the skin [52].

Children naturally tend to loosen their braces, especially during growth spurts. This may seem logical since growth necessitates regular adjustments and renewals of the brace. Milwaukee and Lyon braces are adjustable [2,38). However, this period of growth also presents an opportunity to guide development in a way that better corrects scoliosis. This is known as the "mayonnaise tube" effect, where the brace helps direct growth effectively. The effect is more pronounced in braces with a smooth inner surface, but adjustments can also be made by repositioning the pads within the brace. To ensure the brace remains effective, it is important to schedule check-ups every three months [16].

The straps can rapidly diminish in their efficiency [54]. To circumvent these issues, the ARTbrace employs an anterior overlap of the valves combined with rack-and-pinion closure mechanisms. The versatile Lyon brace is designed with screws that are strategically placed by medical professionals, tailored to the patient's growth patterns. This design simplifies the process of maintaining the corrective alignment of the brace. The concept of time, being the fourth dimension of this brace, plays a crucial role. It is imperative that, in addition to the initial X-ray taken while the brace is worn, the brace undergoes continual monitoring and periodic adjustments (Figure 7).

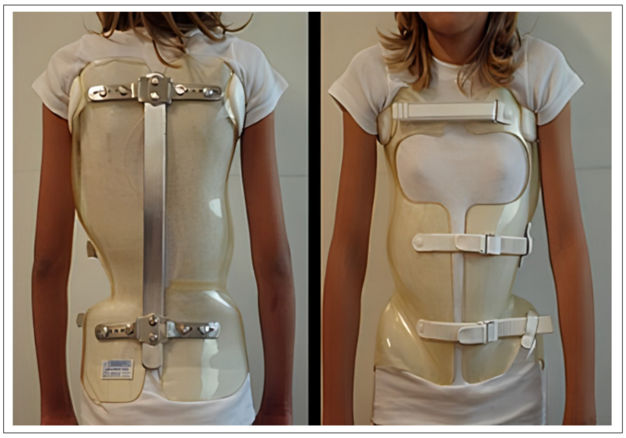

Figure 7: "mayonnaise tube" Effect with Rack-and-Pinion Closure

Ponseti-Type Intervention

Traditionally, the reduction of deformities using plaster cast braces was the standard approach until technological advancements allowed for corrections to be made directly on the patient. An exemplary technique is Min Mehta's serial casting, similar in approach to Ponsetti's method for correcting clubfoot [55].

This method achieves a plastic deformity by lengthening the concavity's ligaments. Subsequently, the correction process can be expedited by metaphorically releasing the "handbrake." Once the brace correction surpasses the 50% mark, the initial phase of "full-time" wear becomes beneficial, aiding in brace adjustment. This is akin to the principle of a wristwatch, the presence of which becomes imperceptible due to the continuous pressure it exerts on the skin [46].

Secondary Mechanism of Action

The secondary mechanisms of action is a non-operating mechanism not part of the core activity. They are essentially outcomes that arise from the initial two mechanisms. These can manifest in adverse forms, like the tubular thorax seen in some cases of juvenile scoliosis. However, they can also be beneficial. The brace acts as a protective shield, serving as a catalyst for epigenetic changes in the environment. It provides crucial support, helping to shape and stabilize the child during the vulnerable phase of adolescence.

Vital Capacity

The reduction in forced vital capacity was found to be 35% for plaster cast braces. In contrast, most braces that exert a comprehensive influence on the thoracic cage result in a 20% reduction [56].

Boston-type braces, which allow full upper thoracic respiration and enhance abdominal breathing, show a 12% limitation. Some braces, such as the Carbon Brace [51], have been designed to reduce the decrease in vital capacity. With the Chêneau brace, where translation serves as the main passive mechanism, thoracic volume remains unchanged. Conversely, when bending is the principal passive mechanism, as occurs with certain other braces, the volumes are altered due to the elongation of the concavity, which aids in restoring normal breathing patterns. Anterior-opening braces use anterior valve overlap along with lumbar lordosis to better regulate abdominal respiration. Additionally, employing high-strength yet less rigid polyamide aids in preserving thoracic breathing capabilities.

After 2 years of treatment, there is no noticeable reduction in vital capacity [57].

Material

There is often confusion between rigidity, resistance and hardness. Our exploration will center around the rigid plastics utilized in trunk braces. Among the most commonly employed materials are polythene and vacuum polypropylene. These materials are favored for several benefits, notably their ability to fit the brace through expansion. However, they are not without drawbacks, such as the propensity to shrink following the thermoforming process. Polymetacrylates offer the unique advantage of allowing screws to be directly fixed by tapping, and their transparency is an added benefit. They necessitate a design akin to a book, featuring hinged openings. In recent developments, polyamides like nylon have emerged, praised for their robust resistance. More importantly, they act as shock absorbers, seamlessly blending transparency and durability, with the added capability of utilizing 3mm thickness and providing greater tolerance, particularly advantageous for adult use [58,16].

Closure

The design of the Milwaukee and Boston braces, featuring a posterior closure, enhances the movement of soft tissues, allows for precise control over pelvic orientation, and encourages effective abdominal breathing. In numerous cases of scoliosis, mechanical correction is typically executed from the lower sections upward. While an anterior closure offers easier access for the patient, it poses challenges, particularly for young women, due to the chest area complicating the stabilization of the mid-thoracic region [54,46] [Figure 7].

Physiotherapy & Gait Modification

The Lyon brace is always used in conjunction with physiotherapy, which complements the action of the brace and compensates for any side effects [2]. When a brace is worn, alterations in one's walking pattern are subtle; however, both speed and rhythm tend to decrease, reminiscent of the cautious pace adopted when wearing a skirt. This adjustment results in a higher energy expenditure while walking. Interestingly, the length of each stride sees an enhancement, which is a beneficial effect, along with the decreased asymmetrical stress often linked to scoliosis [59,60].

There is also an alteration in the functioning of the scapular girdle [60].

Tolerance

A brace that is uncomfortable will inevitably be neglected by the wearer. Several mechanical factors influence the comfort and tolerance of a brace:

a) Surface Area Contact: The extent of the surface area in contact with the body is crucial. Pressure is determined by the force applied divided by the surface area. A larger contact area can help distribute pressure more evenly, enhancing comfort.

b) Initial Full-Time Use: The "watch principle" suggests that consistent, full-time use from the outset can improve tolerance. Gradual acclimatization helps the wearer adjust to the brace more effectively.
c) Shock-Absorbing Quality of the Plastic: The material's ability to absorb shock significantly impacts comfort. High-quality, shock-absorbing plastics can reduce discomfort caused by movement and impact.
d) Adjustability of the Brace: A brace that can be easily adjusted to fit the wearer's body provides better comfort and functionality. Customizable features allow for modifications as needed, ensuring a snug yet comfortable fit.
e) Quality of Molding in the Corrected Position: The precision of the molding process is critical. A well-molded brace that accurately reflects the corrected position will offer better support and comfort [62].

The enduring adaptation of braces to accommodate growth enhances their overall tolerance. Technological breakthroughs in CAD/CAM molding are significantly elevating the accuracy of brace design and their efficacy. However, the most crucial aspect remains the correction performed directly on the patient, reminiscent of the traditional plaster cast braces, which considers the stiffness of the paravertebral structures. This process involves the geometric detorsion of the initial form, followed by the adjustment of this form at both the lumbar and thoracic levels to achieve mechanical detorsion. Consequently, this approach ensures optimal correction within the brace, while the improved precision simultaneously boosts tolerance (Figure 8).

Figure 8: From Left to Right: 1. Geometrical Torsion, 2. Translation below T10, 3. Flexion of T2 to T10. The Sagittal Plane is in Isostatic Balance

Management

Each brace is associated with a control panel comprising tables of indications and decision trees. The protocol for wearing a brace is tailored specifically to each type of brace and is influenced by various factors. These factors include whether there is an initial recommendation for full-time wearing, the angle of the scoliosis, its ability to be adjusted or its flexibility, and the age of the patient. An essential aspect of this protocol is the hyperbolic dose-response curve, which reveals that wearing the brace for 8 hours a day during the weaning phase can achieve up to 90% of the desired outcome, as would be seen with constant use [63]. Medicine is often described as an art, and defining the precise relationship between the effectiveness and the ultimate results remains a challenge yet to be conquered. The rate of patient drop-out serves as a potential indicator of success, with the aim being to prevent any instances of failure. However, it is important to note that for most braces, wearing them does not significantly impact the quality of life for patients.

Active mechanisms serve as a supplement to passive ones. In many cases, it is feasible to reduce or even prevent adverse side effects (Table 2).

Table 2: Active and Secondary Mechanisms of Action

	Active mechanisms of action	**Keywords**
13	Vertebral growth modulation	In-brace correction > 50%
14	Rebalance stress distribution	Mirror technique
15	Active body pulling against gravity	Neck ring / Shoulder corkscrew effect
16	Active pushing / Breathing mobilization	Contact during breathing
17	Elastic forces or levers	Actuators
18	Ponseti-type intervention	Serial casting | Progressive correction | adjustable braces
	Secondary mechanisms of action	
19	Vital capacity	Thoracic growth | Tubular thorax
20	Material / Tolerance	Rigidity - Resistance /Shock absorber | QOL
21	Opening / closure	Anterior / Posterior (sagittal push-up) Velcro / Strap / Ratchet
22	Physiotherapy & Gait modification	Speed / Cadence / energy cost | Stride length / Gait load asymmetry
23	Management	Plastic deformation | Elastic deformation | Progressive weaning for bone mass
24	Monitoring	Compliance

Discussion

The passive mechanisms of spinal braces can be evaluated through immediate X-ray imaging once the brace is applied. Unlike surgical interventions that directly impact the spine at all levels, the T10 vertebra serves as a boundary between two distinct anatomical and physiological mechanisms.

Below the T10 vertebra, the simplest approach involves mechanically adjusting the soft tissue. This adjustment can be achieved by expanding the concave side of the spine, similar to the method employed by the Chêneau brace [64]. The Boston brace is designed to provide a slight flexion combined with a correction of the L5 tilt. This results in an opening of the concavity [65]. The iliac plateau improves translation, but it is difficult to achieve due to the retraction of the polyethylene. In GTB, the positive is turned on its side, with the convexity facing downwards, and the welding is carried out at the level of the iliac plateau [15].

Between T2 and T10, the mechanical action is facilitated by the ribs. A primary concern is the potential ineffectiveness of the brace when compared to surgery, which directly targets the vertebral body. Research by Grivas has demonstrated that thoracic deformation initially occurs before vertebral deformation. This vertebral deformation is secondary to changes in the intervertebral mobility tripod. The ribcage exerts influence on the transverse processes, promoting derotation on either side of the intervertebral disc by stabilizing two vertebrae. The brace directly alters the components responsible for the apical vertebral deformity [66].

The second problem is related to the verticalization of the convexity and the horizontalization of the concavity. The asymmetry begins with this horizontalization, which is accentuated by the translation with expansion in the concavity [67].

Plane geometry plays a crucial role in describing mechanical actions within the three planes of space, particularly in the context of scoliosis treatment. Each plane-frontal, sagittal, and horizontal-has specific methods and effects that contribute to managing this condition.

Frontal Plane
In the frontal plane, two primary methods are employed: translation and flexion. The Chêneau method utilizes translation to push the apical vertebra towards the midline, effectively addressing the curvature. On the other hand, the Lyon Method employs flexion to rehorizontalize the limiting vertebrae, which helps in opening up the concavity of the curve.

Sagittal Plane
The sagittal plane focuses on pelvic retroversion and lordosis, which are essential for achieving a sagittal "push-up." This approach aids in normalizing the distribution at the intervertebral tripod, ultimately enhancing mobility in the frontal plane. In adults, the prognosis for scoliosis is more reliant on the sagittal plane than the frontal plane, making normalization a critical factor for improvement.

Horizontal Plane
In the horizontal plane, derotation is a key objective. This is typically achieved by applying direct support to the hump in a posterolateral sector, which can vary based on the sagittal plane's orientation. The Lyon Method primarily involves using concave chondro-costal support and convex posterior expansion to achieve correction. Derotation is typically performed in a seated position. Additionally, coupled movements in both the frontal and sagittal planes facilitate correction in the horizontal plane.

This method considers the hyperboloid shape of the thorax in its solid geometry approach. Effective detorsion requires a fixed point at the curve's ends, a feature not present in Chêneau-type braces. In contrast, geometric detorsion is the principal mechanism of action for the Milwaukee brace [68].

Advantages of Hyperboloid Modeling in Orthopedic Bracing
One significant advantage of hyperboloid modeling in orthopedic bracing is that mechanical detorsion requires only two orthogonal axes, X and Y. This allows for the definition of two planes, regardless of the curve's nature.

Application of Hyperflexion in Bracing
Hyperflexion is primarily utilized at night. During this time, the pelvic and scapular girdles are integrated into the curve, facilitating hyperflexion. For a single curve, the belts are oriented in the same direction, while for dual curves, they are positioned in opposite directions. When both night and day use is necessary, modifications of the Chêneau brace combine translation and flexion in the plane of greatest curve deformation.

Mobility and Pressure in Braces
Elastic braces offer almost complete mobility, albeit with the downside of constant pressure during movement. In contrast, rigid braces use internal pads to guide mobility, aiding in curvature correction or providing a push-up effect. Some braces are designed without internal pads, allowing for a sliding motion opposite to the direction of scoliosis. This results in varied contact in the three basic positions: standing, sitting, and lying down.

The mechanical action of antigravity relief opposes the biomechanical concept of creep described by Patwardhan [69].

The effectiveness of braces in treating scoliosis is closely linked to the concept of maximizing surface contact, particularly in symmetrical braces. This approach leads to a significant reduction in pressure on the apical vertebra. For scoliosis curves exceeding 40 degrees, symmetrical braces, such as the Wilmington and Sforzesco, are highly effective, offering nearly maximum correction and pressure reduction. Conversely, for curves less than 40 degrees, asymmetrical braces provide better correction.

In the sagittal plane, restoring thoracolumbar lordosis can correct scoliosis in the frontal plane through the interaction of coupled movements. At this point, lordosis contributes to derotation by directly contacting the convex transverse.

The effectiveness of these active mechanisms can be evaluated through X-rays taken without a brace after a minimum period of six months.

The primary goal of all braces is to disrupt the vicious cycle described by Ian Stokes, thereby halting the progression of scoliosis and potentially avoiding the need for surgery. Achieving this requires a brace correction of approximately 50%. A brace that corrects less than 20% is considered ineffective and may have more disadvantages than advantages [70].

Wearing a brace at night facilitates the reshaping of the intervertebral disc by promoting disc rehydration. The primary mechanism involves physiotherapy with the brace, initially focusing on "active axial self-elongation" and avoiding the formation of a hump. The Lyon Method enhances these exercises by reprogramming proprioceptors through ballistic stretching, utilizing the rebound effect of a Swiss ball.

At the thoracic level, the brace incorporates valves that move with respiration, thereby improving costal-vertebral mobility. This feature is particularly beneficial for individuals experiencing excessive stiffness.

To maintain the corrective benefits of the brace over time, it is crucial to have a reliable closure system that retains tension consistently. This system should be effective both in a sitting position, such as during meals, and in a lying position, especially at night. Daytime adjustments are necessary to accommodate growth throughout the year while wearing the brace, ensuring regular repositioning of the pads.

During periods of significant growth in infantile scoliosis, serial bracing is employed, requiring the brace to be worn continuously. As the child enters the pubertal growth phase, the brace is adjusted or replaced for every 5 cm of height gained. Due to the lack of viscoplasticity in the frontal plane, the initial period of wearing the brace is time-limited to prevent stiffening.

Side effects of the treatment are evaluated once it concludes.

While the occurrence of a tubular thorax is rare, it represents a significant drawback of symmetrical braces. Additionally, there is a consistent reduction in vital capacity, necessitating brace renewal even after statural growth has ceased. This is because the rib cage volume continues to expand. Although the absence of lordosis enhances sagittal support, it restricts abdominal breathing, which is typically facilitated by natural lumbar lordosis. The abdominal opening in the brace design helps to improve breathing [71].

High thoracic breathing can be restricted by detorsion braces, which require symmetrical support at the scapular girdle level. However, the ARTbrace offers a solution by allowing children to open the upper anterior closure, providing more flexibility and comfort.

The choice of material for the brace is crucial as it influences how the brace opens. A brace that opens by deformation is simple but often lacks the necessary flexibility for effective curve correction. In contrast, a brace that opens like a book along the posterior pole offers better stabilization of the sagittal plane. This design allows for more precise adjustments to balance curves and accommodate growth, although it may be less aesthetically pleasing. Polyamide 6 is an ideal material for this purpose due to its strength and shock absorption properties, which enhance comfort and compliance.

The closure mechanism also plays a significant role. A back closure is linked to lordosis and a push-up effect, while a front closure is more practical for children. Additionally, an overlapping front closure increases stability and minimizes the shearing effect, making the brace more effective and comfortable for the wearer. Scoliosis can lead to functional asymmetry during walking when not managed with a brace. A brace helps correct this asymmetry and may also influence pelvic rotation.

The effectiveness of a brace largely depends on its mechanical tolerance, which is influenced by several factors. First, for a given force, the pressure exerted by the brace decreases as the contact surface area decreases. Second, the precision and speed of molding the brace are crucial. In some cases, molding is performed while the patient inhales, particularly in adults. Third, when adjustments are made directly on the patient, multiple moldings are often required. Reference points can assist in accurately aligning these corrections.

Adherence to the brace-wearing protocol is vital for its success. Initially wearing the brace full-time facilitates the initial adjustment period, allowing for passive correction, particularly during sleep, by gradually loosening the tension on the concave side of the spine.

When considering daytime brace-wearing for scoliosis, factors such as the angle of curvature, the patient's age, and the rigidity of the spine must be weighed against the potential benefits of wearing the brace for 23 out of 24 hours daily. This decision also involves considering the quality of the patient's musculature. It's important to note that wearing a brace is not a natural condition for the body, particularly during growth periods.

The wide variety of braces available today reflects the diverse nature of scoliosis itself, presenting challenges in both education and practice for ortho-prosthetists. While various generic schools of thought are crucial for learning, in practice, it is impractical to create every type of brace, and not every scoliosis condition can be addressed with a single brace design.

No single brace can encompass all possible mechanisms of action. Therefore, choices must be tailored to the specific characteristics of the patient's scoliosis. Interestingly, the same type of brace can be customized using different mechanisms to meet individual needs. For example, biomechanics indicates that for angulations greater than 40°, geometric detorsion along the Z axis is the most effective mechanism. Below 40°, mechanical detorsion is more effective [72].

The article discusses the complexities and effectiveness of different types of braces, highlighting the challenges in comparing them due to varying protocols and mechanisms. Here's an optimized version: Understanding the effectiveness of braces can be challenging due to the variations in their design and application. Different braces may share the same name but have distinct mechanisms of action, underscoring the importance of their mechanical function. This diversity makes it difficult to directly compare the results of different braces, as each follows unique protocols.

Despite these challenges, some general conclusions can be drawn. Full-time rigid braces have been found to be as effective as nocturnal hypercorrectors, especially when fitted before the age of 12. In contrast, soft braces tend to be less effective than their rigid counterparts [73].

This systematic review is a first step towards a classification of scoliosis braces according to their mechanical action [74].

Conclusion

In summary, this review delves into the mechanical functions of various generic braces, which we have endeavored to categorize systematically. The diverse passive, active, and secondary mechanical actions are designed to address the complex nature of scoliosis, providing a comprehensive solution. It is impractical to converge all potential solutions, necessitating a discerning prioritization that goes beyond merely considering the Cobb angle. Each generic brace is capable of integrating numerous mechanical actions to attain the best possible correction. When physiotherapy is utilized in conjunction with the brace, it can enhance and, to some extent, make up for the mechanical actions that the brace lacks, underscoring the essential need for collaborative teamwork.

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